ESTABLISHING A HIGH PERFORMANCE BASELINE FOR PRE NET-ZERO STATUS COMMERCIAL OFFICE BUILDINGS IN HOT-ARID CLIMATES

By

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Abstract

Energy efficiency and net-zero buildings are becoming household concepts. The race to reduce environmental impacts has produced a boom in research and interest in the topic of clean energy and how to implement it. However, quick implementation without previous example can become difficult. The percentage of net-zero energy buildings is slim and designers are still working toward perfecting the execution. A solid, accepted definition and targets for net-zero energy are essential to ensure to most benefits and the least damage. This thesis investigates the development of net-zero energy performance targets to maximize the efficiency of all buildings.

A base case commercial office building located in Organ Pipe Cactus National Monument was selected to serve as an example for the application of energy efficiency strategies. An essential point bridging the gap between high performance and net-zero energy was defined by comparing existing literature and missing topics regarding high performance. Energy modeling and cost data were used to create a feasible high performance energy target as a marker for a building becoming net-zero ready.

Introduction

Energy consumption and generation is one of the biggest human-caused factors affecting the natural environment. These processes require endless amounts of materials to be harvested from the earth and expel harmful pollutants into the atmosphere. Because a large portion of energy generated is consumed in buildings, a global effort to reduce human-caused environmental damage should include reducing energy consumption by buildings. The construction of net-zero energy buildings has become a primary method of reaching this objective.

The methods and materials used to construct commercial buildings play a large part in determining the amount of energy required to operate that building. These can range from the obvious mechanical and lighting systems that directly use this energy to the not as obvious thermal insulation installed within the building envelope. Therefore, optimizing building methods and materials in each building to minimize energy consumption has the potential to greatly curtail related environmental damage. However, it is not always cost efficient to reduce energy consumption as much as possible. It is important to find a balance between these two metrics for buildings.

Performance requirements set by building codes drive trends in widespread energy consumption. The stricter the minimum requirements, the more efficient buildings will be in an area. However, there is a gap between available, affordable building materials and minimum performance required by building codes and standards, where performance requirements are actually far below what can easily and affordably be achieved in a commercial building. This gap means that those who don’t actively pursue sustainable strategies will most likely only implement what is required because it is most often the most affordable.

The research presented investigates a method to define and implement a cost efficient high performance standard for commercial buildings. This method is intended to provide the greatest amount of energy savings for the least amount of additional cost. By optimizing the balance between cost and performance, it becomes easier to adopt and implement as standard for all future building projects and renovations.

1. Energy and the Environment

Energy is an integral part of any system, from the individual person to society as a whole. Developed societies rely on energy for nearly all facets of daily operation. Energy is required for the buildings we live in and the various means of transportation we use. This heavy reliance has been steadily growing for decades, and is projected to continue growing if no changes are made to current habits. This energy demand stems from several factors.

1.1 Population and Urbanization

One factor is the dramatic rise in population experienced in recent years across the United States. The United States population has nearly doubled in the past 60 years [1]. This statistic, coupled with the fact that the United States uses the most energy per capita and has the third highest population globally [2,3] highlights the need for adaptation in the energy sector. In addition, population is expected to increase by 30% by the end of the century [4].

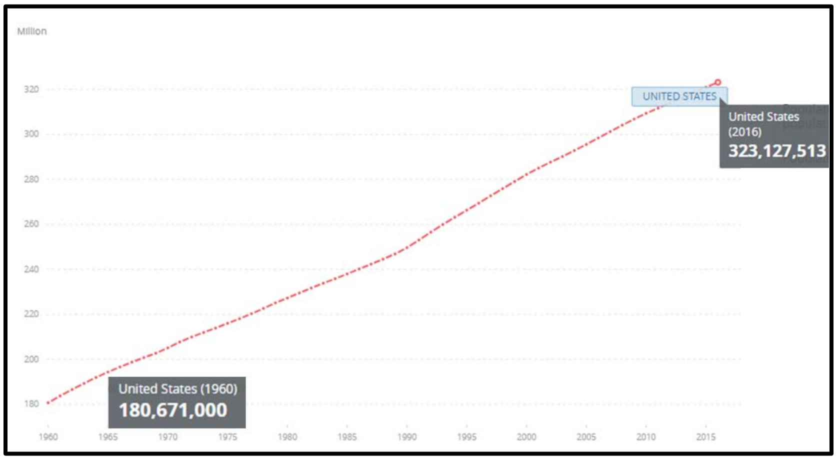


Figure 1: United States Population, 1960 – 2016 [1]

A second factor affecting energy demand is urbanization. Urbanization is the process of physical growth in urban areas [5], meaning an increased amount of buildings and concrete covering the natural landscape and consuming energy. Urban development increased by a factor

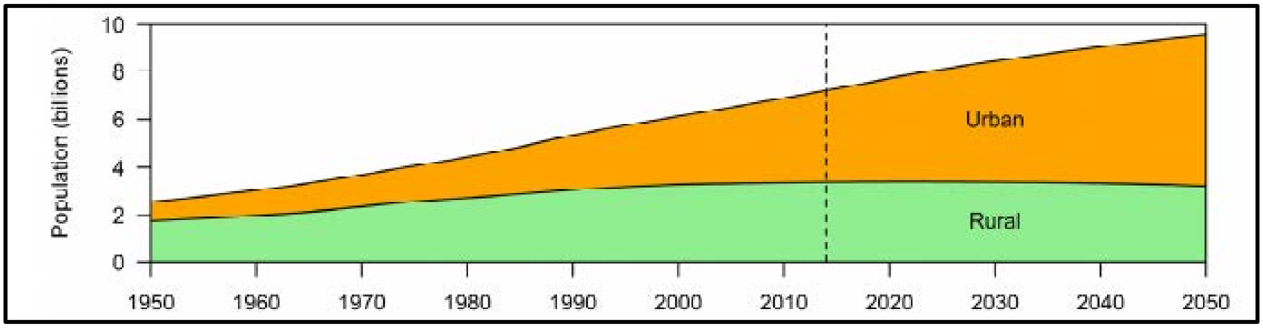


Figure 2: Projected Urban Growth and Rural Decline [6]

of five between 1950 and 2014 and is expected to increase by another 60% by 2050 [6].

1.2 Energy Demand and Impacts

As both population and urbanization figures continue to rise, projected energy consumption follows along the same pattern, shown in figure 3. More people transporting to and occupying more buildings brings more consumption. Currently, buildings are responsible for 40% of the total energy consumption in the United States [7].

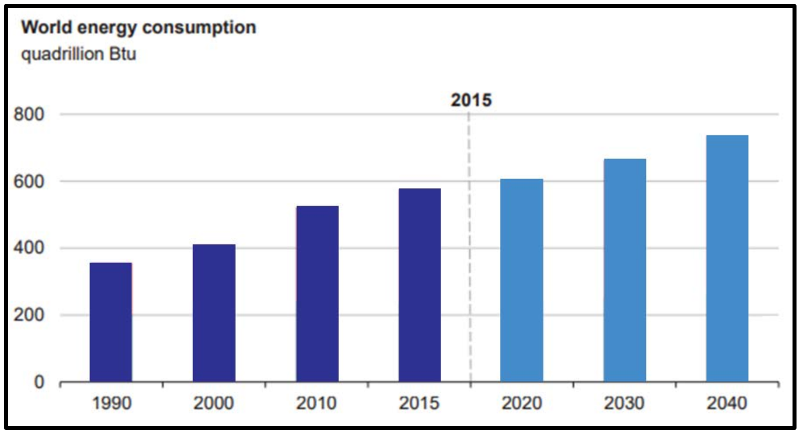


Figure 3: Projected World Energy Consumption [8]

The energy is supplied by several sources, but only 10% of that energy is sourced from clean, renewable energy sources. This means that almost 90% of the energy consumed in the United States is from fossil fuels [9]. Fossil fuels such as oil, coal, and natural gas are non-renewable resources that can be burned in order to produce energy. The burning of fossil fuels releases carbon dioxide and other greenhouse gases into the atmosphere, and because they are our primary source of energy

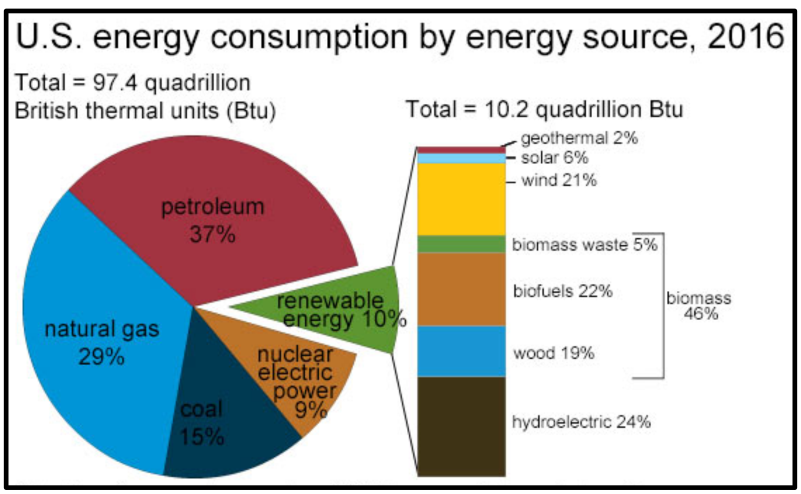


Figure 4: U.S. Energy consumption by Source [9]

generation, about 75% of human caused emissions in the past twenty years have resulted from the burning of fossil fuels [10].

Greenhouse gas emissions are extremely detrimental to our environment and can have long lasting effects. Greenhouse gases are so called due to their ability to absorb radiation and trap heat in the atmosphere, causing a global rise in temperatures. These gases released by human activity are also partially responsible for creating holes in the natural layers of ozone in the atmosphere that protect plant and animal life from solar radiation. In addition, highly urbanized areas producing greenhouse gases are more susceptible to smog and pollution, not only harming the environment but increasing health risks for the population of those cities. Carbon dioxide emissions have almost doubled since 1970 and the United States has been responsible for about 15% of the total global emissions [11]. At only 4.4% of the world population [12],

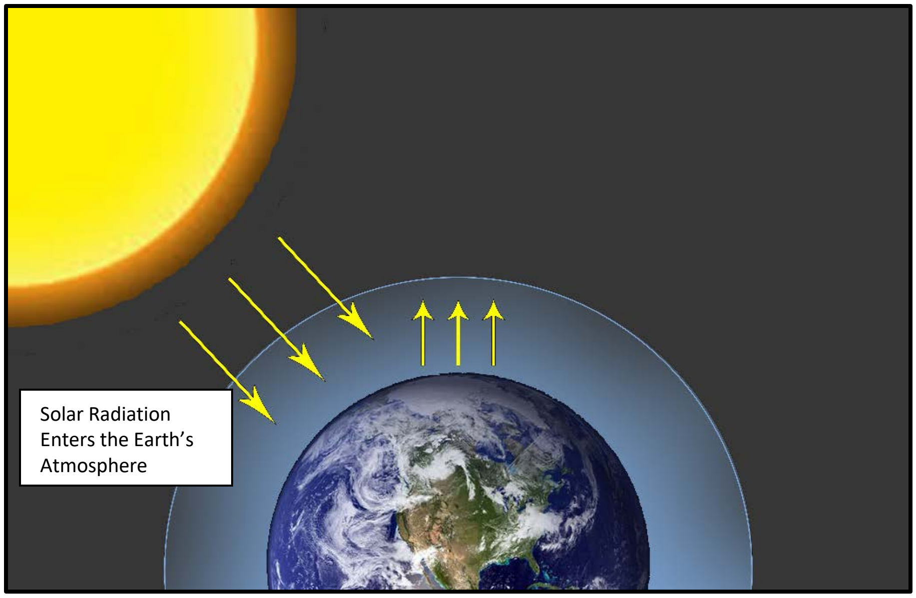


Figure 5: Depiction of Greenhouse Effect

Figure 6: Air Pollution in China [13]

there is a great imbalance in contributions to global emissions between the United States and other countries. This problem must be addressed. As coal is burned to power commercial buildings in New York or Philadelphia, carbon dioxide readings are increasing on the other side of the planet. None of these systems, no matter how far apart on the globe, work in a vacuum and therefore must be addressed globally rather than on an individual basis.

While the use of coal, one of the largest energy source contributors to greenhouse gases, has been decreasing to a plateau over the past few years, energy demand continues to grow. Though the fossil fuel alternatives to coal most certainly do not produce as many harmful pollutants, they still cannot be considered the most favorable solution to balance energy needs with environmental impact.

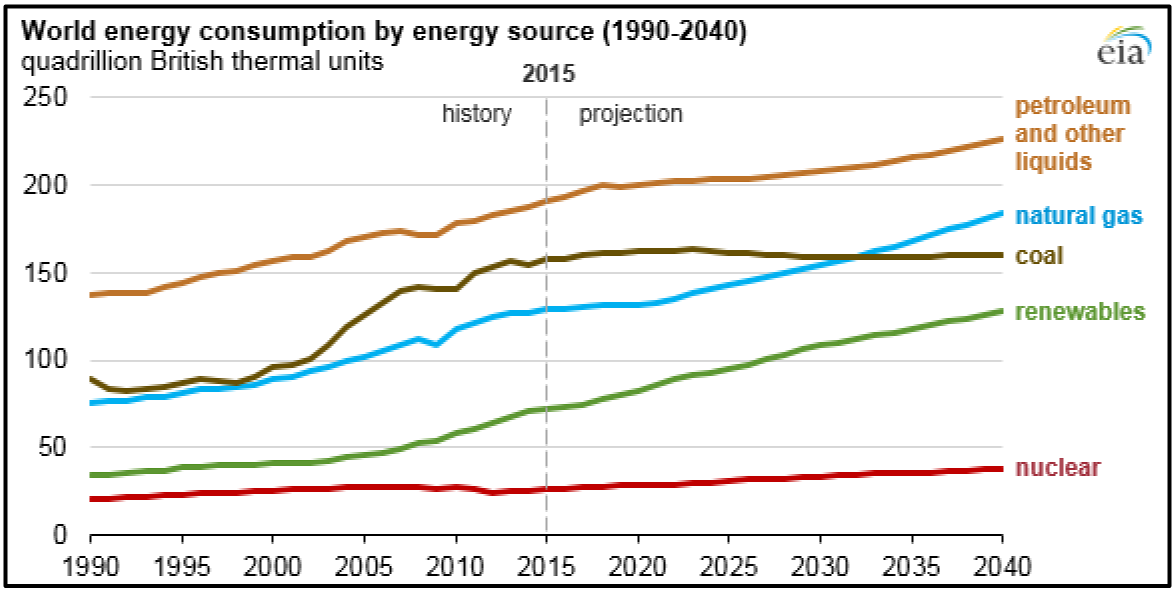


Figure 7: Energy Consumption Projections by Energy Source [14]

1.3 Renewable Energy Generation - Photovoltaics

Just since 2005, the total capacity for renewable energy has more than doubled, indicating an acknowledgement of the harmful effects of primarily relying on fossil fuels and a push towards a cleaner energy source [15]. Though currently only a small percentage of energy generated around the globe, renewable energy is potentially the solution to reversing human caused impacts on the environment. Renewable energy is energy generated from rapidly renewable sources. This means that the resource replenishes on a human timescale and essentially never run out. Fossil fuels on the other hand take millions of years to form and are often depleted faster than they are generated. Renewable energy can be generated from a variety of sources, including using available wind, hydropower, biomass, and geothermal energy. All of these energy sources can be used to generate electricity, cool or heat a building, or provide fuel for transportation [16].

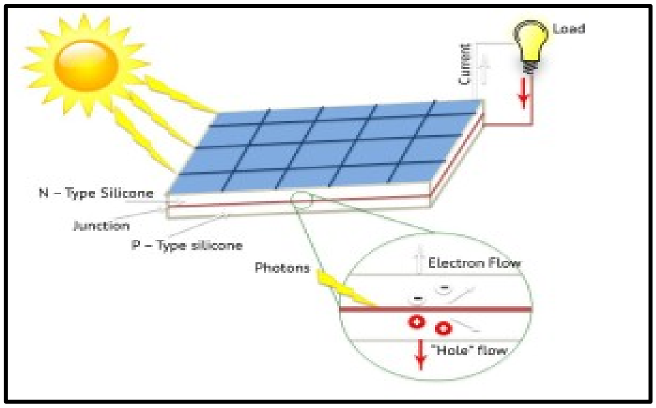


Figure 8: Energy Generation in Photovoltaic Cells [18]

One of the most widely available renewable energy sources is solar energy. The majority of plant and animal life is dependent on energy from the sun in order to function. Plants utilize energy from the sun for a process called photosynthesis to produce sugars and grow. Animals can indirectly use the same solar energy by consuming the plants grown by the sun or directly as a source of essential vitamins that prevent various health issues. Buildings have long used direct sunlight to heat interior spaces prior to the advent of mechanical systems.

A more modern application of solar energy is the conversion of light from the sun into electricity using photovoltaics. This form of technology was a much needed step towards reducing human cause carbon emissions, as the operation of the panels in generating electricity does not produce pollution or carbon emissions, unlike fossil fuels. Each panel is constructed of a semiconducting material, such as silicon, that absorbs sunlight and can transfer that energy to electrons so they are able to flow through the material as an electrical current [17]. Rather than pulling energy from the grid, a building can utilize this energy generated on site and reduce reliance on fossil fuels for energy. At 40% of the total energy consumption in the United States, this has great potential for mitigating global carbon emissions.

The downside is that photovoltaics’ ability to generate electricity is dependent on the availability of direct sunlight, meaning clouds and times when the sun is set limit the output potential for photovoltaic systems. Any electricity needed when there is no solar radiation available must be supplemented by other means, usually coal or another fossil fuel. This relationship also means that even if a building uses a renewable energy source but also has a high energy demand, it is still directly causing hefty amounts of carbon emissions. The solution for buildings then is to reduce the demand for energy as much as possible, then move to renewable energy production.

2. High Performance Buildings

Since the environmentalism movement in the middle of the 20th century, our society has been looking for methods of protecting the natural environment and reducing any further damage caused by human activities. In 1987, the United Nation's World Commission on Environment and Development, also known as the Brundtland Commission, introduced the concept of sustainable development and the ideals that must be adhered to in order to ensure a more livable future. Sustainable development is defined as development that meets the needs of the present without compromising the ability of future generations to meet their own needs [19]. While vague, this definition brings up a couple of important points that shapes how buildings have been adapted to meet this requirement in the times since the report was published. One concept that this definition identifies is human need in relation to consumption. In meeting the needs of the present, it is necessary to obtain and consume resources. People need food, water and shelter in order to survive, so some consumption is unavoidable. The second half of the definition highlights the mindset that all members of society should have going forward. Consuming only the amount of resources that leaves enough for future generations to also meet their own needs. Refraining from permanently damaging the natural environment so it continues to perform its function well beyond our lifetimes.

With this mindset and the identification of carbon emissions as one of the largest threats to the planet, global efforts have been pursued with the goal of minimizing each country's contribution of harmful pollutants to the atmosphere. The 2030 challenge is one such effort. In 2002, Edward Mazria set a series of targets for reduction of greenhouse gas emissions culminating in zero emissions by the year 2030. His mission was to rapidly transform the built environment from one of the largest contributors of greenhouse gas emissions to a primary part of the solution [20]. Through the refinement of several of these movements, high performance buildings began to emerge throughout the built environment.

A high performance building is a building that integrates and optimizes all major high-performance building attributes, including energy efficiency, durability, life-cycle performance, and occupant productivity [21].

2.1 Qualities

In order to judge whether or not a building successfully qualifies as a high performance building, the National Institute of Building Sciences developed the Whole Building Design Guide. This guide outlines several qualities that are necessary for a building to achieve high performance and address present issues within the built environment. It calls on designers and developers to consider the entirety of a project, from the obtaining of resources all the way through operation of the building and eventually demolition. These qualities include accessibility, aesthetics, cost-effective, functional, historic preservation, productive, secure, and sustainable [22].

Figure 9: WBDG Design Objectives [22]

Accessibility involves adapting the building for total occupant equity. Addressing the needs of disabled occupants means that the building will be able to be used by the greatest number of people.

Aesthetic quality of the building considers the physical appearance of elements integrated into the building.

Making the building cost-effective weighs building design options against each other based on cost in order to determine the most feasible choices and stay within the determined budget set for the project.

The functionality of the project is defined as how well the space is programmed for current use and how the spaces can be adapted for any future changes in programming.

Historic preservation acknowledges the qualities of a city that make it unique and aims to protect them for future generations.

A productive building allows occupants maximum physical and psychological comfort to enhance overall health and well-being. This is accomplished through proper lighting, air distribution and workspace organization.

The security of a design pertains to how well it protects occupants from natural and man-made hazards.

Sustainability measures the environmental performance and impacts of a building.

2.2 High Performance Energy and Energy Standards

Embedded within the sustainability category of the Whole Building Design Guide is the optimization of energy performance in order to reduce energy related carbon emissions. However, without a specific target in mind, it is hard to visualize what the optimized energy performance of a building is or what strategies will get a building to that point.

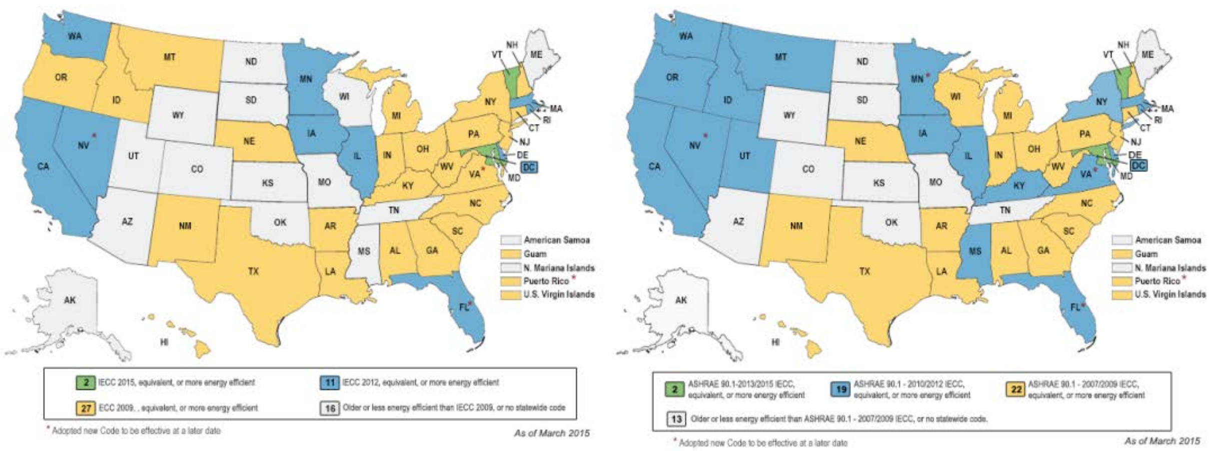


Figure 10: Map Showing Adoption of Residential and Commercial Building Codes [24]

Energy standards are a relatively new tool for directly affecting the energy performance of buildings. The Energy Policy Act of 1992 was one of the first policies to require states to adopt some sort of standard for energy regarding new buildings and renovations [23]. Because building codes dictate minimum performance, they create huge potential for energy savings. They overcome financial barriers, negating the decisions of builders to use cheaper, less efficient options. The codes currently adopted across the United States are estimated to have saved about 30% in energy consumption compared to when the codes were first required in 1992. They are also credited with saving about $44 billion dollars for consumers and 300 million tons in the same time frame [24].

Though energy efficient buildings are becoming more and more common, they are still far off from being the norm. Buildings are still only being designed to minimum requirements which are cost-effective, but not tailored to meet the aggressive goals set for the year 2030. Several organizations have attempted to create design standards for high performance buildings. Rather than just giving a definition, they begin to set out performance goals for buildings. One such standard is the Leadership in Energy and Environmental Design criteria (LEED). These guidelines were set by the United States Green Building Council and give a series of categories for buildings to earn points in, encouraging the same whole building design approach envisioned by the WBDG. The Energy and Atmosphere category in LEED is focused on energy consumption and carbon emissions and, having one of the biggest impacts out of all of the categories, is worth the most points [25]. This category sets out a range of energy reduction targets, the least amount of points given for a 6% reduction in energy use and the greatest amount of points given for a 50% reduction in energy use.

TABLE 1. Points for percentage improvement in energy performance

New Construction	Major Renovation	Core and Shell	Points (except Schools, Healthcare)	Points (Healthcare)	Points (Schools)
6%	4%	3%	1	3	1
8%	6%	5%	2	4	2
10%	8%	7%	3	5	3
12%	10%	9%	4	6	4
14%	12%	11%	5	7	5
16%	14%	13%	6	8	6
18%	16%	15%	7	9	7
20%	18%	17%	8	10	8
22%	20%	19%	9	11	9

Figure 11: Table Determining the Amount of Points Received in LEED v4 for Energy Performance

If set at the right target, similar to the LEED v4 guidelines, codes and standards have great potential to increase energy performance of all existing and planned buildings. In order to get the most out of them, higher performance standards must be made requirements rather than voluntary programs.

3. Net-Zero Energy Buildings

In the category of high energy performance, net-zero buildings have become one of the highest milestones to achieve for buildings. A select few designers have taken on the challenge of going above and beyond high performance, and the number has been rapidly increasing over the years. A common definition for a net-zero building is a building that produces enough renewable energy to meet its own energy consumption on an annual basis. While the goal of this definition remains true to the spirit of high performance and reducing carbon emissions, the execution of these buildings in practice has not always been perfect.

The definition simply indicates that renewable energy must meet energy demand, meaning that this can be exploited if enough money is available for the developer. By simply adding enough renewable energy, any inefficient building can be considered net-zero energy and that doesn't solve the root of the problem that net-zero energy buildings are striving to solve [26].

Figure 12: Inefficient Net-Zero Energy Building [27]

A drawback to using many of the available renewable energy sources is that many of them are not accessible at all times of the day. Solar energy is obviously only available when the sun is, and wind power directly varies with the wind currents. Without the ability to store that clean energy, it must be used as it is generated on site or exported to the grid to be used elsewhere. The remaining energy that is needed when renewables are not available comes from the grid as energy generated from fossil fuels. Considering the case of the inefficient net-zero energy building, the flaw of the definition defined above becomes even more obvious and calls on building owners to think more critically about how their building impacts the environment. As the inefficient case operates, it could easily generate more energy than needed and overload the grid. A large amount of energy from fossil fuels would still be needed to power the building when renewables were unavailable. If using solar panels, the amount needed could easily be double what the same building would need if energy efficiency was prioritized, increasing investment costs and requiring significantly more resources.

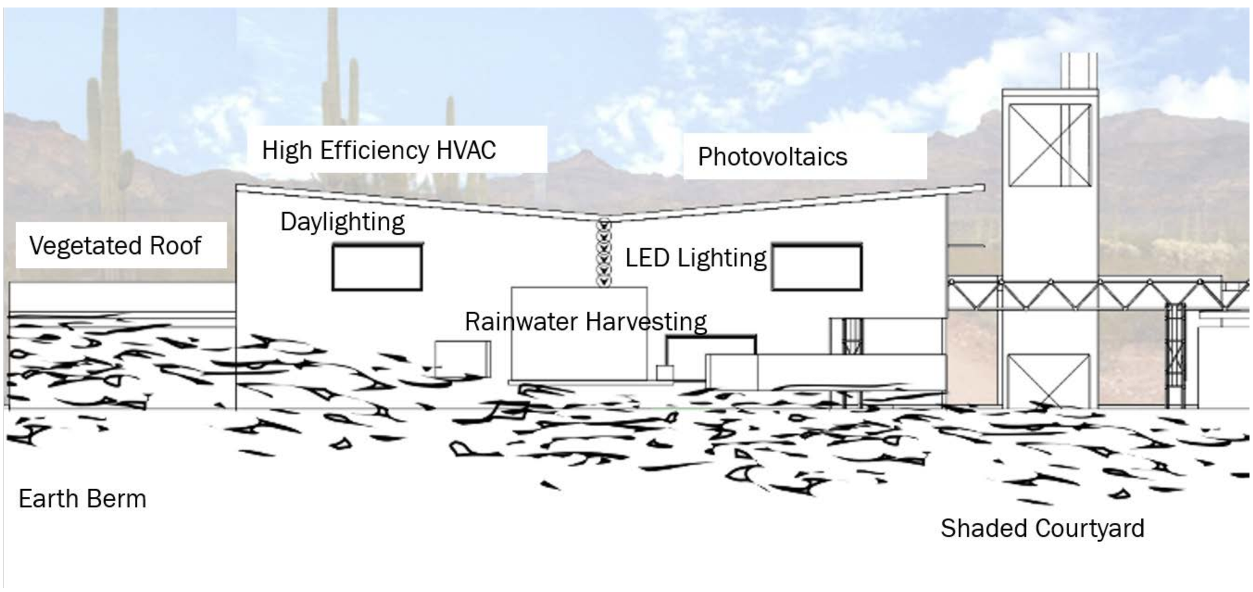


Figure 13: Highlighting the Implementation of Energy Efficiency Strategies in a Net-Zero Building

The U.S. Department of Energy collaborated with a variety of organizations interested in energy performance and the development of net-zero energy buildings in order to create a common definition that more accurately indicates how these buildings should be created. This common definition is “An energy-efficient building where, on a source energy basis, the actual annual delivered energy is less than or equal to the on-site renewable exported energy" [28]. By including the phrase energy efficient in the beginning of the definition, this definition solves the problem of inefficient buildings being considered as net-zero and forces a more thoughtful and holistic approach for buildings. These buildings now require the application of a variety of energy efficient strategies to reduce total consumption prior to adding any renewable energy system.

3.1 Energy Efficiency Strategies

In order to properly save energy, efficiency strategies must be fully understood in context. The following are strategies identified most often in existing energy codes for buildings in hot a dry climates (i.e. ASHRAE Climate Zone 2B). Strategies will be sorted into two fundamental categories: passive strategies and active strategies. Passive strategies are those that do not require energy input from external sources (such as the grid) to function and are most often integrated within the building envelope. Active systems are upgrades made to building systems that use energy to operate. Both types of strategies have their own benefits and disadvantages to consider. Passive systems often require little maintenance but are more difficult to change later while active systems require expensive maintenance more often but can be equipped with advanced analytical software to measure performance on an hourly basis. Additionally, there is a cost difference for installation. Passive strategies are often less expensive than active just to purchase. One important consideration in selecting strategies is the order of implementation. It is often more beneficial to begin implementing passive strategies prior to active strategies. This isn't just because of the cost. Passive strategies will reduce the energy demand of a building and require less work the active strategies in the same way that implementing all energy efficiency strategies before putting a renewable energy system on the building will reduce the required amount of renewable energy generation.

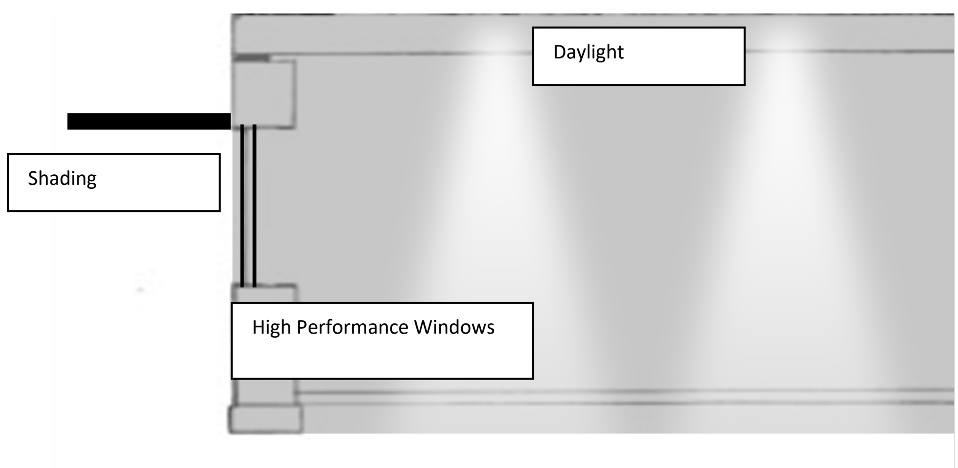


Figure 14: Passive Strategies Example

Passive Energy Efficiency Strategies

The following is a list and description of several energy efficiency strategies implemented throughout hot and dry climates. It is not a complete list of strategies that can be used, but it provides a starting point for creating a more efficient building.

1- *High Performance Windows*

In energy codes, the performance of window assemblies is measured by two values: the U-Value and the Solar Heat Gain Coefficient. The U-Value indicates how well a material is as insulation from heat [29]. The Solar Heat Gain Coefficient is an indication of how much solar radiation is transmitted through a window [30]. These values are adjusted by changing several facets of the assembly. These factors include the number of panes of glass, whether or not there is a coating on the glass and where it is located, what is between the panes of glass if there are multiple, and the frame that the glass is attached to. In a cooling dominated climate, both values should be as low as possible, meaning that the least amount of heat is entering the building through the windows.

2- *Shading Devices*

Shading devices often accompany high performance windows to reduce glare and direct sunlight. The type and dimensions of shading devices installed for windows depends on the dimensions and orientation of the related window. Shading devices can be vertical, horizontal, or a combination of the two. Optimal shading dimensions allow direct sunlight during under-heated periods, during winter for example, and blocks all direct sunlight during overheated periods, during summer months.

3- *Daylight*

Daylighting brings available light into a space to replace the need for artificial lighting during the day. Careful consideration must be taken to only introduce daylight rather than direct sunlight which carries heat. Daylighting opportunities must be adjusted to minimize glare and evenly distribute light throughout the space. Some effective daylighting strategies include adding skylights to bring light into central spaces away from vertical windows and light shelves to reflect light off of the ceiling.

4- *Natural Ventilation*

Natural ventilation takes advantage of the wind currents available on site to cool buildings and move air using operable windows without the assistance of a mechanical system. Natural ventilation can be enhanced by adjusting window sizes, window placement and building geometry to increase volume and velocity of air moving through a space.

5- *Raised Floor System*

Raised floors create the opportunity for other strategies to become more efficient and spaces to become more flexible, causing an indirect energy efficiency benefit. They separate the floor from the slab to create a crawlspace in between. In relation to energy consumption, a raised floor allows vents from mechanical systems in the floor rather than in the ceiling like more traditional distribution systems. Cool air no longer has to fight against rising hot air to reach the occupants and can be cooled to a temperature closer to the desired temperature (ex. instead of cooling air to 50°F for the occupant to feel the air at 75°, the air only needs to be cooled to 65°).

6- *Thermal Mass*

Thermal mass materials are materials with a high capacity for storing heat. In warm climates, these materials can be used on the exterior and interior spaces to absorb heat during the warmest points throughout the day and then release the heat again several hours later when it is cooler.

7- *Insulation*

Insulation is any material with the ability to stop or slow heat flow. Insulating materials are installed between any two spaces where minimal heat transfer is desired, for example between an outdoor space and a conditioned space. Any transfer that occurs creates additional need for conditioning from the mechanical system, increasing the energy consumption.

3.2 Upfront and Operation Costs

An important factor to keep in mind about implementing various strategies is how the cost relates to the energy performance. Buildings have several costs associated with them. One is the upfront cost, meaning the amount of money that the buildings costs to construct. Another is operation costs, which covers utility bills and maintenance over the lifetime of the building. Selecting different strategies will often increase the total initial cost of the building but will reduce the operation costs due to lower energy consumption. The application of individual energy efficiency strategies conform to the law of diminishing returns, which states that as one factor increases, the output per unit of the factor will eventually diminish [31]. For example, as increased amounts of insulation are applied to a building, the cost for that strategy continues to increase, but the additional energy savings will be less than the last iteration [32]. There comes a point where it is no longer cost effective to upgrade that strategy and investments should be made elsewhere.

The cost of reaching net zero energy will always come at a higher initial cost. This appears to be a barrier for most people in implementing net-zero energy and high performance strategies. Many who avoid energy efficiency strategies seem to simply be unaware of how small the cost increase has become in the past few years, making any cost hurdle nearly nonexistent. In addition, the benefits beyond reducing human impact on the environment are not as emphasized as they should be when marketing strategies [33]. These strategies improve health and comfort for the people in the building and save money in the long run on top of reducing carbon emissions. Savings in operating costs allow a flexible, multi-step approach to reducing energy consumption. Savings accumulated each year can be used to reinvest for more strategies until the building cannot be optimized any further [34].

3.3 Defining a Pre Net-Zero Status

In the analysis of high performance and net-zero energy buildings, the definitions do not clearly explain what an optimized level of energy efficiency is. At what point should designers stop investing in energy efficiency and instead invest in renewable energy? Setting out a clear definition for this point is important for proper execution of the related principles. For net-zero energy buildings, this point can be identified as the pre net-zero status or net-zero ready status. Mentioned in a previous section, there is a point where energy efficiency strategies are no longer worth the investment. This, in combination with optimizing energy performance, can be used to establish a definition for pre net-zero status for buildings.

A pre net-zero status building can be defined as a building that has optimized all energy efficiency strategies to a point where it is no longer cost effective to implement further upgrades prior to the implementation of active renewable energy systems.

4. Research Questions

Considering the information gathered from the literature review, this research thesis aims to address the following questions:

- How affordable are net-zero energy buildings?
- How are energy efficiency strategies selected?
- What should building energy performance be before adding renewable energy systems?
- Which metric is best used to determine optimum capability for renewable energy in commercial buildings?

5. Research Idea

In examination of available information on carbon emission reduction and energy efficiency, an often overlooked component of reaching the lofty goals of net-zero energy for buildings is a specific goal and indication of the steps that need to be taken to reach that goal. This observation inspired the following ideas driving the research in this thesis:

-By comparing upfront cost to energy savings, a point of minimum performance can be determined where it is no longer cost effective to upgrade energy efficiency strategies.

-By setting adefinitive high performance goal, it will be easier to design buildings capable of addressing carbon and energy issues in the built environment.

The point identified where it is no longer cost effective to upgrade energy efficiency strategies is the point where a building has achieved pre net-zero status. Steps taken during research and analysis aim to identify this point as a measurable indication of whether a commercial office building is ready for a renewable energy system.

6. Research Methodology

This research employs a multi-step approach with the goal of establishing a baseline measurement indicating whether or not a building is at the optimum energy performance to implement a renewable energy system. Preparation for the steps involved case study research and proposed design site surveys.

Step 1. Create an energy model of example building designed to meet minimum code requirements

Step 2. Determine baseline energy consumption

Step 3. Select energy efficiency strategies based on parameters highlighted in building code

Step 4. Determine energy savings for incremental upgrades of each energy efficiency strategy

Step 5. Determine cost increase for each upgrade

Step 6. Plot cost increase versus energy savings in order to determine the point of diminishing return

Step 7. Combine optimum points into single case

Step 8. Identify performance goal to be achieved in commercial office buildings – EUI

Step 9. Organize strategies based on cost and energy savings for a simplified strategy selection process

7. Hot-Arid Climate Case Study: DPR Construction Phoenix Regional Office

The DPR Construction Phoenix Regional Office became the first net-zero energy building in the state of Arizona in 2011, renovated from an old adult boutique into a living laboratory of green design.

Figure 15: DPR Construction Regional Office in Phoenix, AZ [35]

The ideas for renovating the existing space came from the collaboration between multiple companies and a multidisciplinary team. The primary focus became using passive strategies in the desert, first and foremost. Using passive methods of operating the space saved most of the energy, the rest made up by implementing renewable energies. Design began with the envelope of the building. Large operable windows and skylights implemented in the design immediately reduced the need for artificial lighting by roughly 80% while maintaining the lighting level required for work. Insulation was added to the wall and roof assemblies and the exteriors were given a reflective coating to reduce heat gain.

Natural ventilation techniques were combined into a series of strategies feeding off of one another. Cooling towers use water and gravity to passively cool outside air, feed the cooled air through the large expanses of glass in the façade throughout the space. A large metal structure on the roof collects heat in a location higher than the supply opening. As the structure heats up, it pulls the cooler air across the room, providing passive conditioning for the occupants.

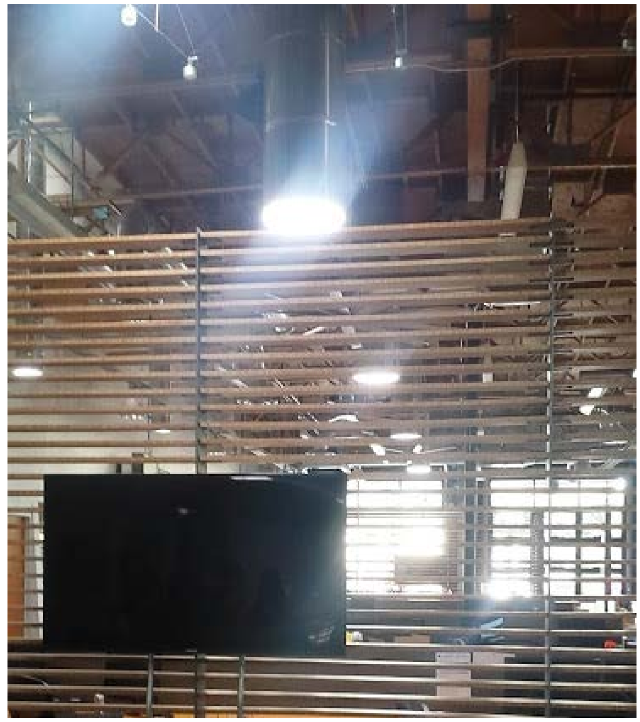


Figure 16: Daylighting Strategies Used Within DPR Construction Phoenix Regional Office, by author

Occupants adjusted personal comfort preferences and allowed for thermostats to be set to larger minimum and maximum points reducing the time that the HVAC system is running during the year. The elimination of plug loads was accomplished by hooking up every piece of equipment that does not need to be continually turned on to a master 'vampire' switch. This switch allows the last person to leave the building to shut down all of the plug loads when no one will be using them.

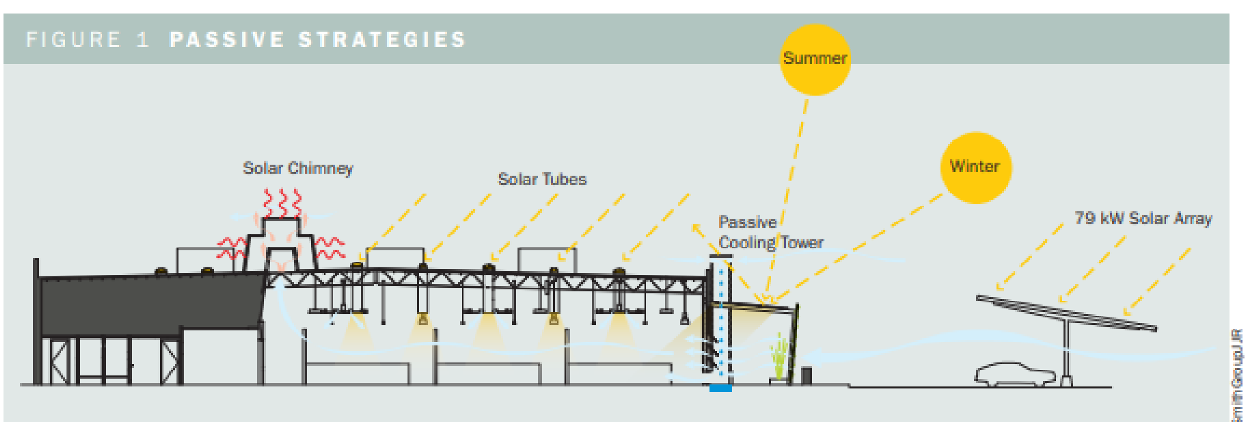


Figure17: Section highlighting environmental Strategies [36]

Final considerations were given to increasing the efficiency of the mechanical system. This was accomplished through proper sizing, increasing the SEER rating of the units and real time monitoring of energy consumption.

After all of the energy efficiency strategies, the building required a 79kW PV array in order to cover the rest of the energy consumption in the building. Strategies were carefully thought out and implemented to fit within a desert climate. Optimizing passive cooling strategies cut down energy consumption for the majority of the year, with the exception being in the summer when it becomes much more difficult to operate using only passive systems. The building's final site energy consumption was 26.8Btu /ft2 before photovoltaics. This energy consumption beat the ASHRAE Standard 90.1-2007 by roughly 45% at only 15% additional cost. The company is expecting an 8-10 year payback period which is generally a favorable amount of time for return on investment.

Figure 18: Renewable Energy at DPR Construction Phoenix Regional Office [36]

8. Organ Pipe Cactus National Monument

The House Energy Doctor program at the University of Arizona was given a 3-year contract to redesign several built up portions of the Organ Pipe Cactus National Monument. The following is information about the site and the baseline building design developed from site survey efforts.

Organ Pipe Cactus National Monument is a desert preserve located in Ajo, Arizona, in the southwestern part of the state adjacent to the U.S./Mexico border. This site is located in climate zone 2B – hot and dry.

Figure 19: Location within State

Figure 20: Extent of the Park

` The buildings existing on site are commercial office buildings designated for the Resource Management and Law Enforcement Offices in the park. The first task in the project was site analysis to inform the design.

Figure 21: Bird's Eye View of Site


Figure 22: Buildings targeted for redesign


Figure 23: Bird's Eye View of Maintenance Yard

Design restraints were created based on the existing structures and occupants. Floor area of new construction had to be equal to or greater than the existing floor area and the new construction must be able to accommodate the current functions. A nearby area of scarred land was chosen as a proposed site for the new building.


Figure 24: Proposed Site (Facing North)


Figure 25: Proposed Site (Facing West)

Proposed Design

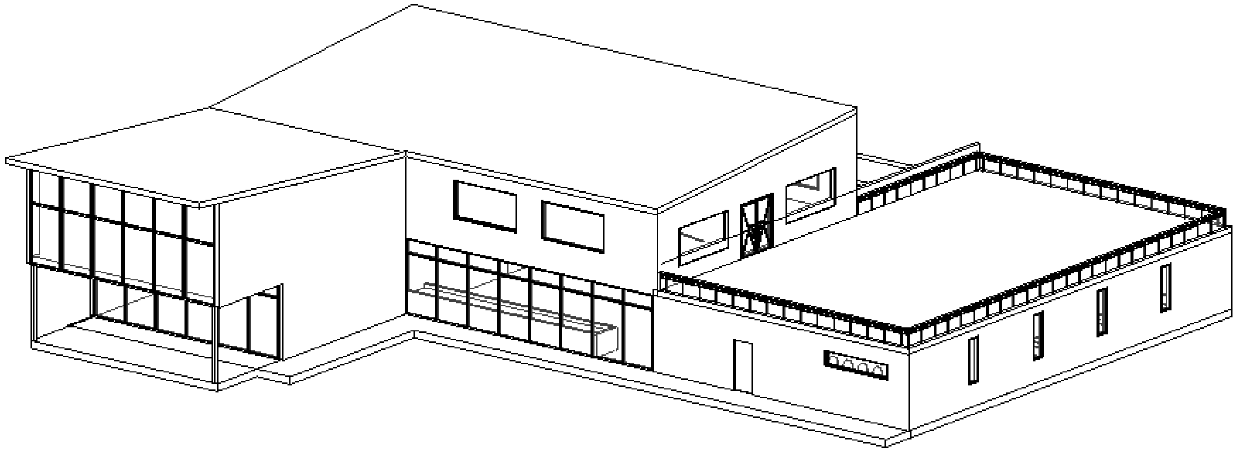


Figure 26: South-East View

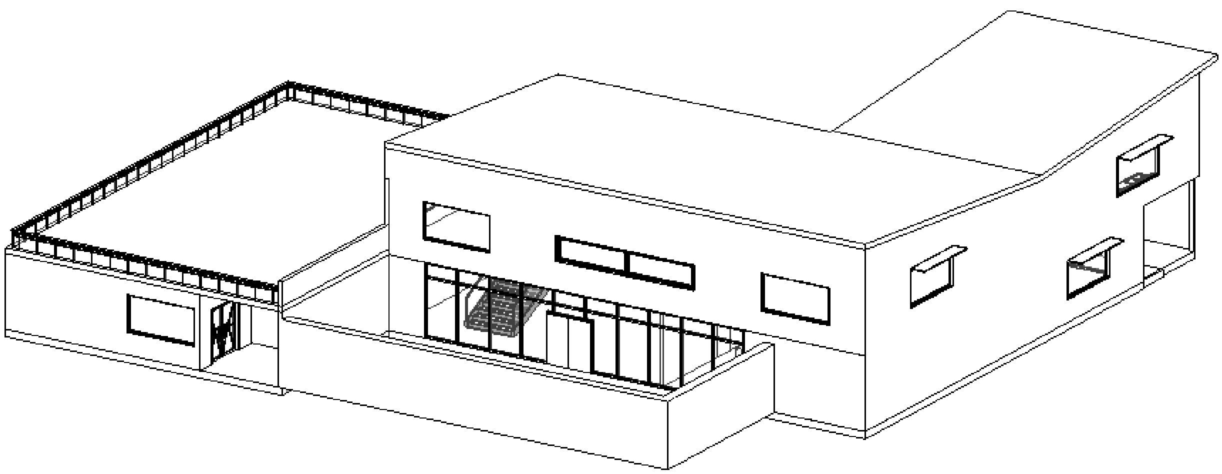


Figure 27: North-West View

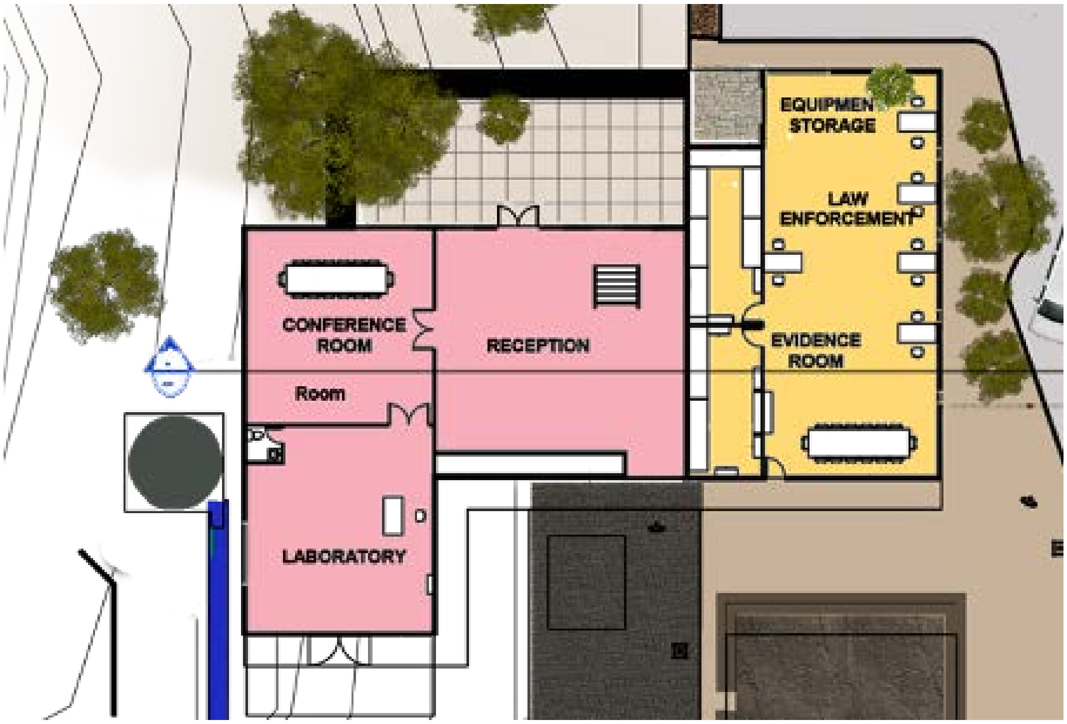


Figure 28: First Floor Plan

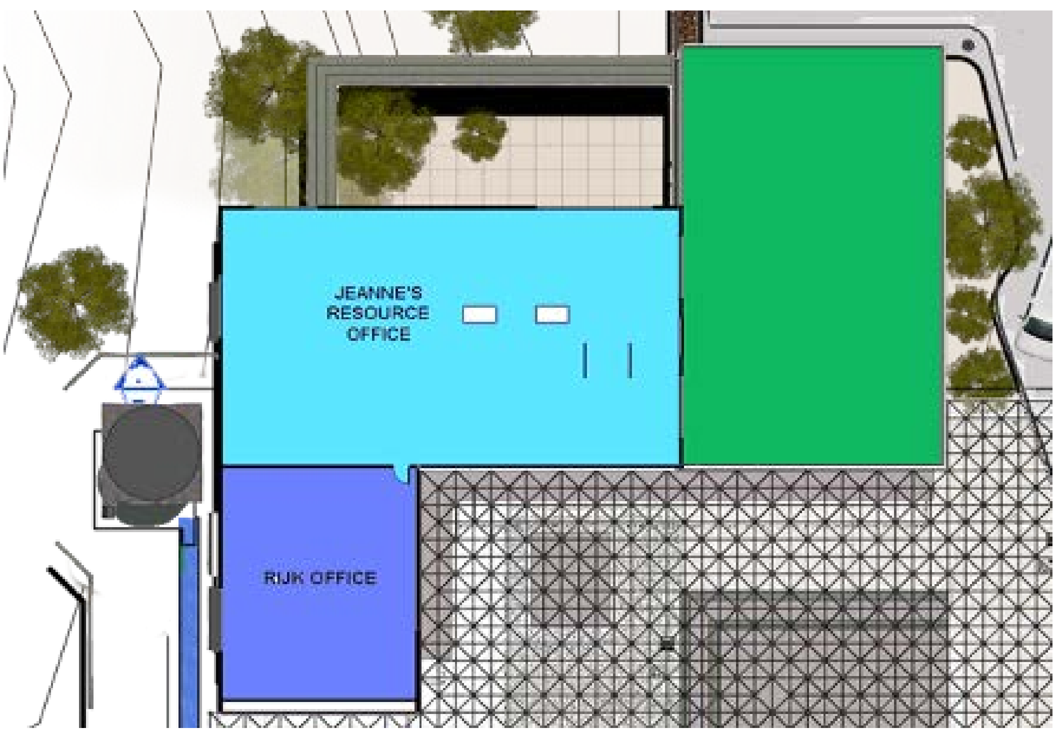


Figure 29: Second Floor Plan

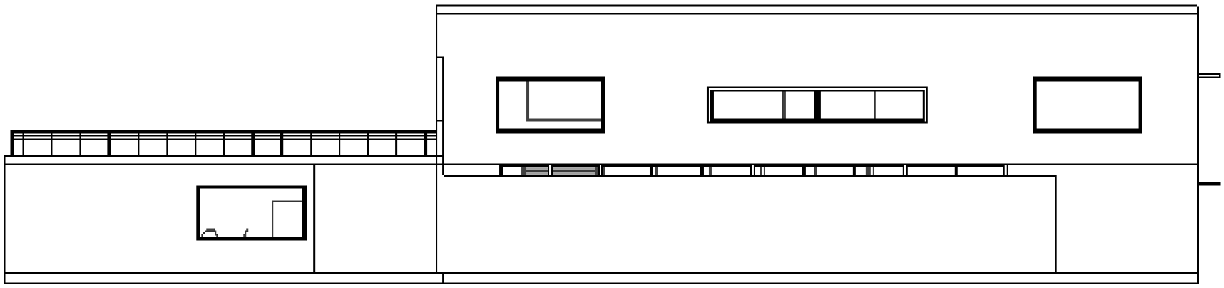


Figure 30: North elevation

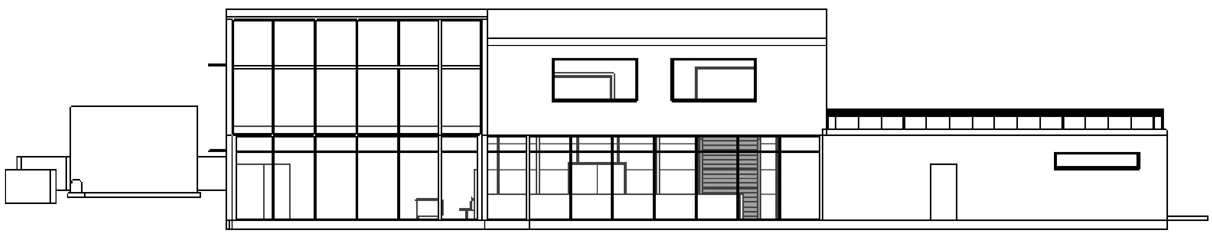


Figure 31: South Elevation

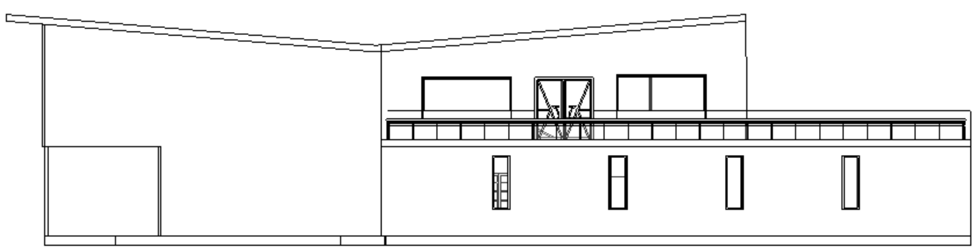


Figure 32: East Elevation

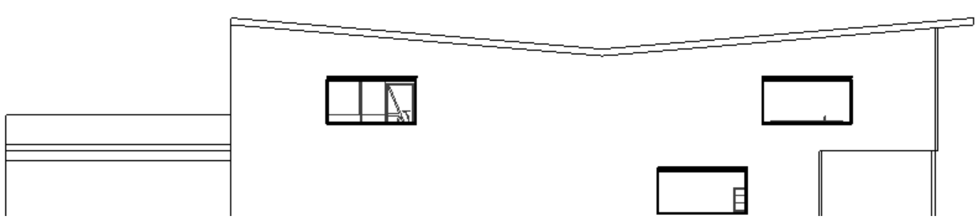


Figure 33: West Elevation

Building Schedule

1	**Building Name**: Resource Management and Law Enforcement **Address**: 10 Organ Pipe Dr., Ajo, AZ 85321
2	**City: Location**: Ajo (Lat. 31.95, Long. -112.80, elev. 1673.6) **Degree Days**: HDD65 =1678 & CDD50 = 6921 (ASHRAE Standard 90.1, 2010 page 151) **Utility Rates**: Electric = 0.13 $/KWh – Natural Gas = 1.1 $/Therm
3	**Climate Zone**: "2B" for Pima (ASHRAE Standard 90.1, 2007 page 110)

		SHELL I	SHELL II	TOTALS
4	**Orientation**	South	South	
5	**Volume**			
	Conditioned Space	46200 ft^3	36400 ft^3	82600 ft^3
6	**Areas**			
	Roof	3850 ft^2	2600 ft^2	6450 ft^2
	Conditioned Floor	6150 ft^2	3850 ft^2	10000 ft^2
	Walls			
	South	1320 ft^2	980 ft^2	2300 ft^2
	West	780 ft^2	1050 ft^2	1830 ft^2
	North	1320 ft^2	980 ft^2	2300 ft^2
	East	1080 ft^2	1050 ft^2	2130 ft^2
	Total	4500 ft^2	4060 ft^2	8560 ft^2
	Windows			
	South	840 ft^2	516 ft^2	1356 ft^2
	West	48 ft^2	96 ft^2	144 ft^2
	North	612 ft^2	156 ft^2	768 ft^2
	East	48 ft^2	160 ft^2	208 ft^2
	Total	1548 ft^2	928 ft^2	2476 ft^2
	Doors			
	South	20 ft^2	--	20 ft^2
	West	42.2	--	42.2
	North	42.2 ft^2	--	42.2 ft^2
	East	--	42.2 ft^2	42.2 ft^2

<table>
<tr><td></td><td>Perimeter</td><td>400 L.F.</td><td>290 L.F.</td><td>690 L.F.</td></tr>
<tr><td>7</td><td>Ratios
Glass to Floor
S Glass to Floor</td><td>
26.92%
13.65%</td><td>
24.3%
13.40%</td><td>
24.76%
13.56%</td></tr>
<tr><td>8</td><td colspan="4">Insulation:
• Roof: R-20 continuous insulation, U-value = 0.048
• Walls (Exterior): 6in Slump Block Construction, Continuous insulation R-12, U-Factor = 0.052
• Doors: Insulated Metal, U-value = 0.2 (Exterior) & Wood, U-value = 0.2 (Interior)
• Windows: Metal Frame, U-value = 0.69, SHGC = 0.25</td></tr>
<tr><td>9</td><td colspan="4">Shortwave Reflectance:
Roof: Medium Abs = 0.55, Walls: Medium Abs = 0.2</td></tr>
<tr><td>10</td><td colspan="4">Infiltration: 0.65 CFM/ft^2 (external wall area)</td></tr>
<tr><td>11</td><td colspan="4">HVAC Size:
• (2) Split System – 5kbtuh
• (1) Packaged – 5kbtuh
Efficiency:
• SEER 14.00
Fan Schedules: 6am to 3pm, no Fan Night Cycling
Thermal Zones: 3 Zones: First Floor Resource Management, Second Floor Resource Management, Law Enforcement
Thermostat: Occupied: Cooling (Office) = 80°F, Heating = 60°F</td></tr>
<tr><td>12</td><td colspan="4">Lighting Power Density (LPD):
• Building Area Type: Offices = 1.0 W/ft^2</td></tr>
<tr><td>13</td><td colspan="4">Equipment Load: office = 0.7 W/ft^2</td></tr>
<tr><td>14</td><td colspan="4">Domestic Water Heating: GE Electric Water Heater GE06P06SAG, 6 Gallons, 2000 Heater Watts, no recirculation</td></tr>
<tr><td>15</td><td colspan="4">Building Operation: 6am to 3pm, Close: Sat + Sun + 10 default holidays</td></tr>
</table>

9. Energy Model Simulation

Prior to simulating the building in a software for energy performance, the building must be run through a software called COMcheck in order to see whether or not the building passes code. In this case, the building is checked against the IECC 2012 code which is the minimum requirement for buildings in the area. The objective was to ensure that the building not only passed but only passes by the smallest amount possible. The baseline building passed all three measures categories in COMcheck, for envelope (passed by 3%), interior lighting (passed by 1%) and exterior lighting passed by 3%. These indicate successful compliance with code and we can proceed with energy simulations and energy efficiency runs.

COM*check* Software Version 4.0.8.1

Envelope Compliance Certificate

Project Information

Energy Code:	2012 IECC
Project Title:	Resource Management and Law Enforcement
Location:	Ajo, Arizona
Climate Zone:	2b
Project Type:	New Construction
Vertical Glazing / Wall Area:	29%
Skylight / Roof Area	2%

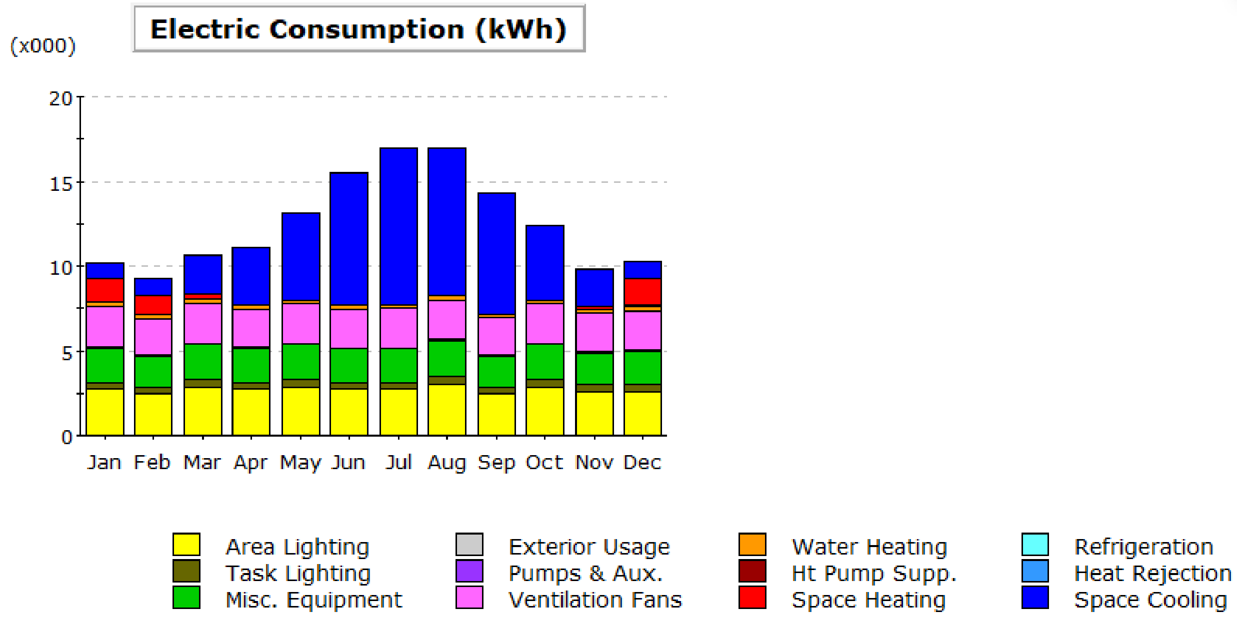
Construction Site:	Owner/Agent:	Designer/Contractor:
10 Organ Pipe Dr. Ajo, AZ 85321	U.S. National Park Service	Andrew Leyva

Envelope PASSES: Design 3% better than code

Interior Lighting PASSES: Design 1% better than code

Exterior Lighting PASSES: Design 3% better than code

Figure 34: COMcheck - IECC 2012 Code Compliance



Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	0.97	0.99	2.33	3.35	5.14	7.88	9.23	8.76	7.10	4.40	2.23	0.98	53.37
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	1.34	1.08	0.24	0.02	-	-	-	-	-	-	0.11	1.57	4.36
HP Supp.	0.02	0.03	0.00	-	-	-	-	-	-	-	-	0.08	0.13
Hot Water	0.27	0.25	0.29	0.27	0.26	0.23	0.21	0.21	0.18	0.22	0.22	0.24	2.85
Vent. Fans	2.35	2.12	2.35	2.27	2.35	2.27	2.35	2.35	2.27	2.35	2.27	2.35	27.63
Pumps & Aux.	0.07	0.06	0.02	0.01	-	-	-	-	-	-	0.02	0.06	0.23
Ext. Usage	0.06	0.05	0.05	0.05	0.04	0.04	0.04	0.06	0.06	0.06	0.06	0.06	0.64
Misc. Equip.	1.98	1.79	2.07	1.98	2.07	1.98	1.98	2.15	1.81	2.07	1.89	1.90	23.67
Task Lights	0.42	0.38	0.44	0.42	0.44	0.42	0.42	0.46	0.38	0.44	0.40	0.40	5.02
Area Lights	2.73	2.47	2.86	2.73	2.86	2.73	2.74	2.98	2.48	2.86	2.61	2.61	32.66
Total	10.21	9.24	10.65	11.09	13.16	15.54	16.97	16.98	14.29	12.39	9.81	10.25	150.57

Figure 35: Baseline Energy Simulation Results

The table and chart above show the energy consumption of the building designed to minimum IECC 2012 code requirements. The results indicate where the majority of energy is being consumed in the building and will dictate which parameters are chosen to be adjusted in order to increase energy savings. The baseline building's annual energy consumption is 150,570kwh/yr which translates to a 52 kbtu/sqft/yr EUI. Based on the high cooling and lighting loads, the strategies selected focus on these areas of building performance:

Some of these parameters cannot be simulated incrementally, they are simply applied on the building or not. The parameters that can be adjusted incrementally will be simulated at each performance level in order to show the decreasing incremental savings at each point.

Envelope Reflectance	Interior Blinds
Insulation Value	Daylighting Controls
Airtightness	Comfort Setbacks
High Performance Windows	High Efficiency Lighting Fixtures
Shading Devices	High Efficiency HVAC System

High Performance Windows

Annual Energy USE or DEMAND

0	Base Design	1,542	156.42	150,568
1	0+DBL low e	1,516	153.82	148,068
2	0+Triple low e	1,462	148.35	142,798
3	0+quadruple low e	1,434	145.45	140,012

Incremental SAVINGS **(values are relative to previous measure (% savings are rela**

1	0+DBL low e	26	2.60 (2%)	2,500 (2%)
2	0+Triple low e	80	8.07 (5%)	7,770 (5%)
3	0+quadruple low e	108	10.97 (7%)	10,556 (7%)

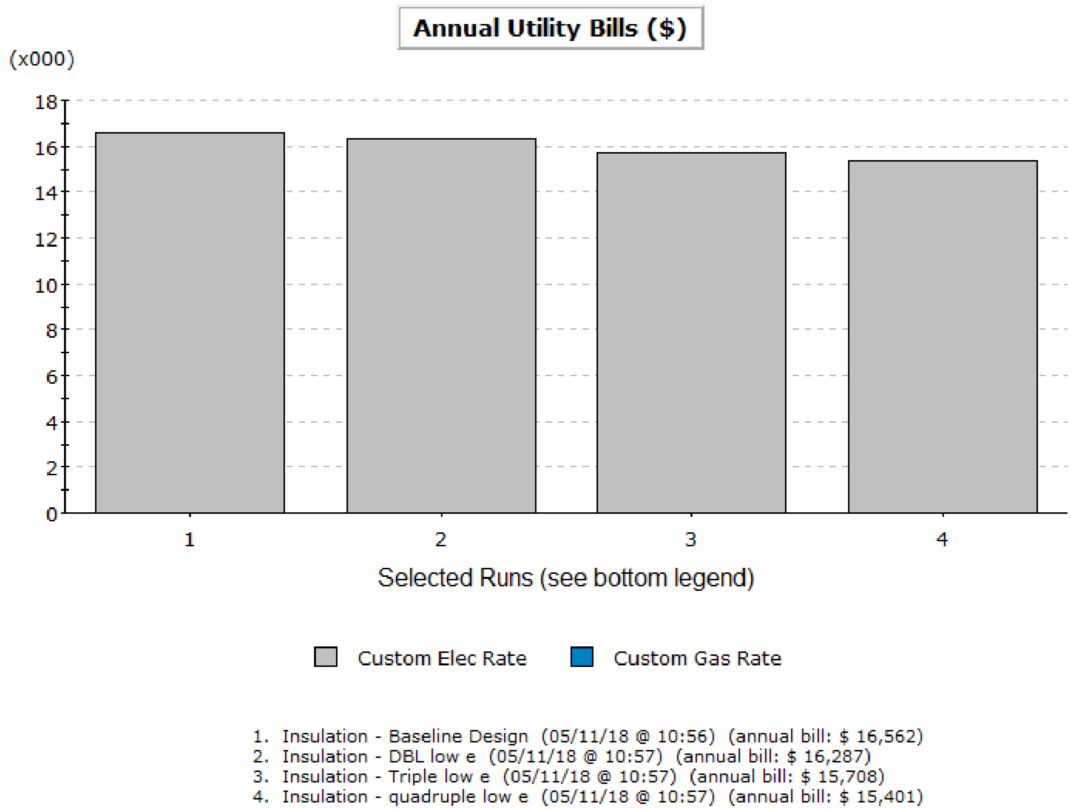


Figure 36: Utility Bills - High Performance Windows

High Efficiency Lighting Fixtures

Annual Energy USE or DEMAND

0	Base Design	1,542	156.42	150,568
1	0+DBL low e	--	--	--
2	0+Triple low e	--	--	--
3	0+quadruple low e	--	--	--
4	0+25% lighting	1,469	149.04	143,471
5	0+50% lighting	1,298	131.69	126,767
6	0+75% Lighting	1,178	119.52	115,049

Incremental SAVINGS **(values are relative to previous measure (% savings are relative to b**

1	0+DBL low e	--	--	--
2	0+Triple low e	--	--	--
3	0+quadruple low e	--	--	--
4	0+25% lighting	73	7.37 (5%)	7,097 (5%)
5	0+50% lighting	244	24.73 (16%)	23,801 (16%)
6	0+75% Lighting	364	36.90 (24%)	35,519 (24%)

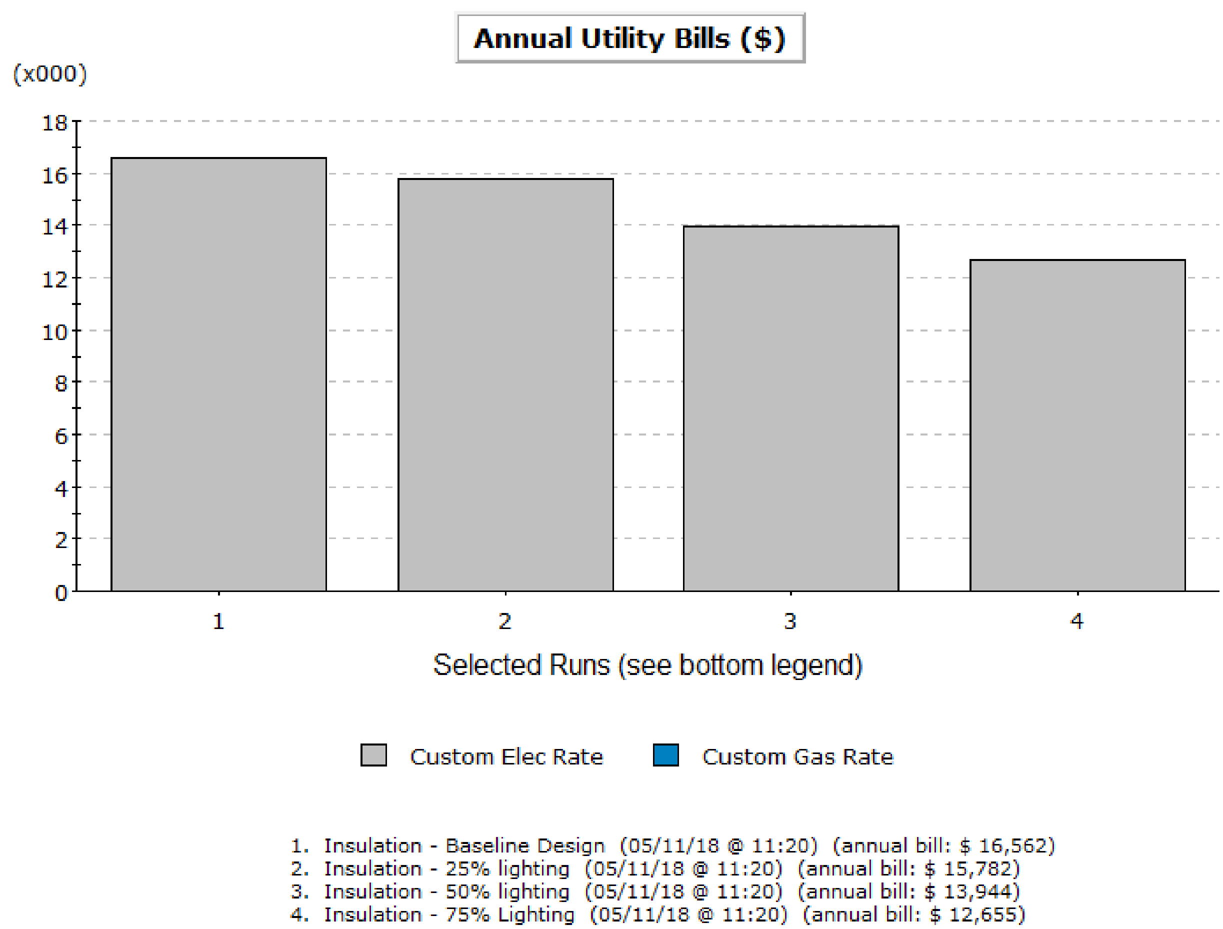


Figure 37: Utility Bills - High Efficiency Lighting

High Efficiency HVAC System

Annual Energy USE or DEMAND

0	Base Design	1,542	156.42	150,568
7	0+Seer 14	1,494	151.56	145,893
8	0+Seer 15	1,452	147.31	141,803
9	0+Seer 16	1,415	143.59	138,218
10	0+seer 17	1,383	140.30	135,053
11	0+seer 19	1,326	134.54	129,505
7	0+Seer 14	48	4.86 (3%)	4,675 (3%
8	0+Seer 15	90	9.11 (6%)	8,765 (6%
9	0+Seer 16	126	12.83 (8%)	12,350 (8%
10	0+seer 17	159	16.12 (10%)	15,515 (10
11	0+seer 19	216	21.88 (14%)	21,063 (14

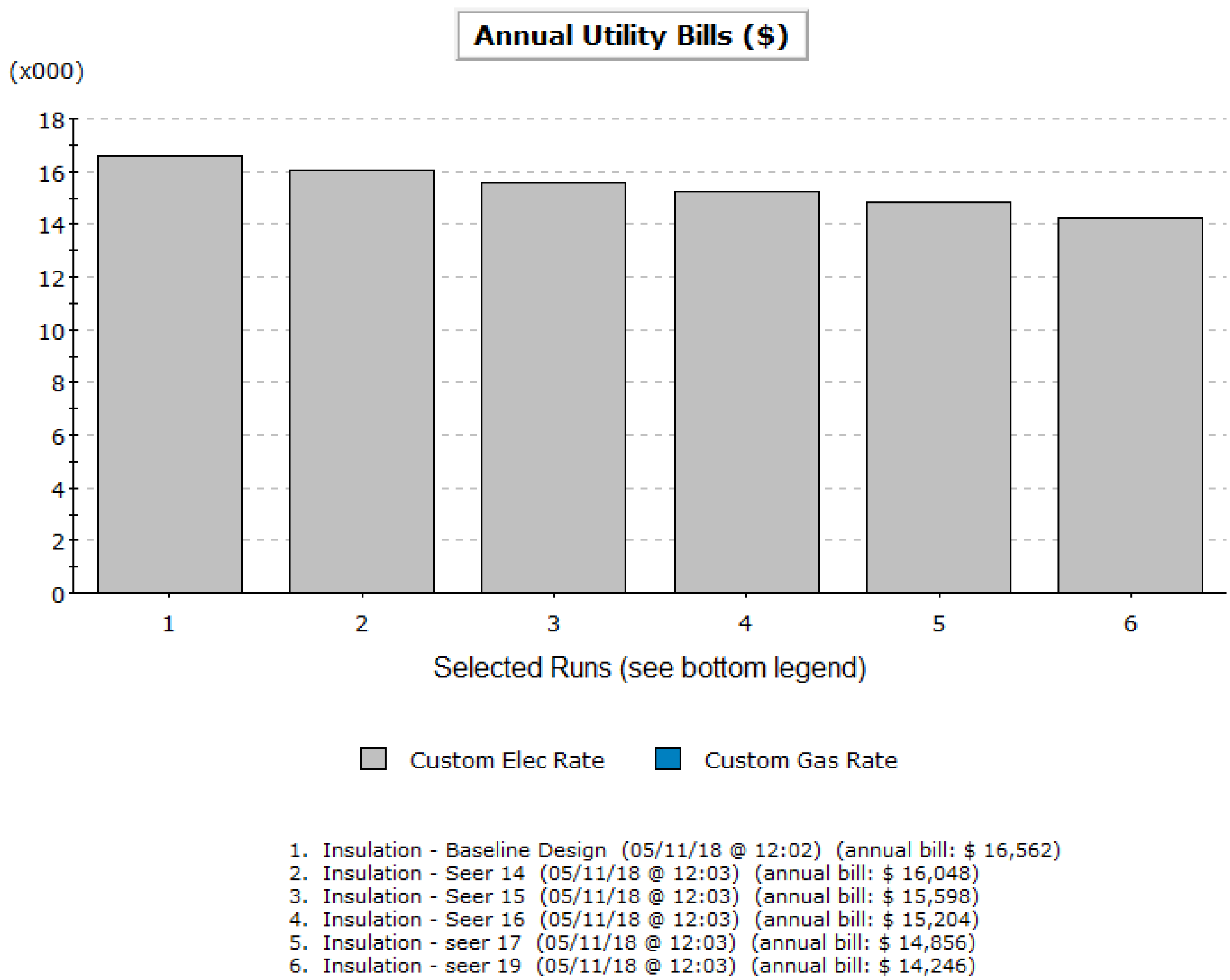


Figure 38: Utility Bills - High Performance HVAC

The results from the energy model indicate that each subsequent strategy applied had diminishing savings compared to the last. For example in improving the SEER rating of the HVAC system, the first change resulted in 48kwh saved, the next upgrade only yielded 42kwh more, then 36kwh. Comparing the costs of each of these strategies, we can determine the point at which it no longer becomes worth the investment for the energy savings. At this point, initial costs are too high to justify the energy savings.

The next energy model iterations combined the strategies at each step of performance shown above into a combined case at each level. The groups were separated by cost and energy savings (low cost, low savings – high cost, high savings). This was done in order to develop a phasing strategy for high performance design. The first group of strategies could be implemented by themselves to save 15%. That 15% savings can then be reinvesting into the building in order to get the second set of upgrades that will save an additional 10% and so on. This model should be considered in the early design phases in order to maximize savings once construction is complete.

15% total savings

Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	0.13	0.14	1.04	1.90	3.46	6.12	7.64	7.29	5.53	2.65	0.97	0.19	37.07
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	1.30	1.04	0.20	0.01	-	-	-	-	-	-	0.06	1.44	4.04
HP Supp.	0.02	0.03	0.00	-	-	-	-	-	-	-	-	0.07	0.12
Hot Water	0.27	0.25	0.29	0.27	0.26	0.23	0.21	0.22	0.18	0.22	0.22	0.24	2.85
Vent. Fans	1.80	1.63	1.80	1.74	1.80	1.74	1.80	1.80	1.74	1.80	1.74	1.80	21.23
Pumps & Aux.	0.07	0.06	0.02	0.01	-	-	-	-	-	-	0.02	0.07	0.25
Ext. Usage	0.06	0.05	0.05	0.05	0.04	0.04	0.04	0.06	0.06	0.06	0.06	0.06	0.64
Misc. Equip.	1.98	1.79	2.07	1.98	2.07	1.98	1.98	2.15	1.81	2.07	1.89	1.90	23.67
Task Lights	0.44	0.40	0.47	0.44	0.47	0.44	0.44	0.49	0.40	0.47	0.42	0.42	5.31
Area Lights	2.73	2.47	2.86	2.73	2.86	2.73	2.74	2.98	2.48	2.86	2.61	2.61	32.66
Total	8.81	7.87	8.79	9.14	10.96	13.29	14.86	14.99	12.21	10.13	7.99	8.80	127.84

- Total Electric Consumption: 127.84 (kwh x000)
- Site EUI: 44.3 KBTU/SQFT-YR GROSS-AREA
- Source EUI: 132.8 KBTU/SQFT-YR GROSS-AREA

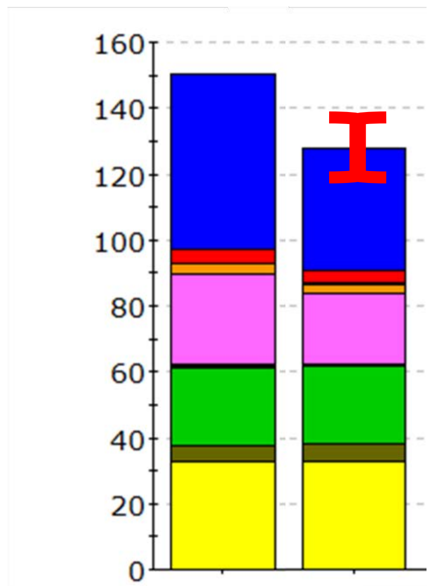


Figure 39: 15% Energy Savings Run

25% total savings

Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	0.06	0.07	0.64	1.37	2.84	5.45	7.09	6.71	4.83	2.06	0.67	0.10	31.88
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	1.35	1.04	0.17	0.00	-	-	-	-	-	-	0.03	1.43	4.01
HP Supp.	0.02	0.03	0.00	-	-	-	-	-	-	-	-	0.07	0.12
Hot Water	0.27	0.25	0.29	0.27	0.26	0.23	0.21	0.21	0.18	0.22	0.22	0.24	2.85
Vent. Fans	1.52	1.37	1.52	1.47	1.52	1.47	1.52	1.52	1.47	1.52	1.47	1.52	17.85
Pumps & Aux.	0.07	0.06	0.02	0.01	-	-	-	-	-	-	0.02	0.07	0.25
Ext. Usage	0.06	0.05	0.05	0.05	0.04	0.04	0.04	0.06	0.06	0.06	0.06	0.06	0.64
Misc. Equip.	1.98	1.79	2.07	1.98	2.07	1.98	1.98	2.15	1.81	2.07	1.89	1.90	23.67
Task Lights	0.44	0.40	0.47	0.44	0.47	0.44	0.44	0.49	0.40	0.47	0.42	0.42	5.31
Area Lights	2.37	2.07	2.38	2.19	2.25	2.15	2.18	2.38	2.00	2.38	2.22	2.29	26.88
Total	8.14	7.14	7.60	7.77	9.44	11.76	13.47	13.52	10.75	8.77	7.00	8.09	113.46

- Total Electric Consumption: 113.46 (kwh x000)
- Site EUI: 39.3 KBTU/SQFT-YR GROSS-AREA
- Source EUI: 117.9 KBTU/SQFT-YR GROSS-AREA

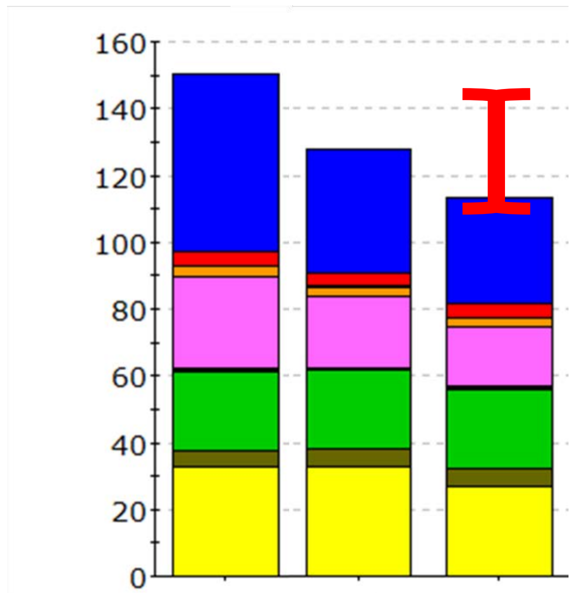


Figure 40: 25% Energy Savings Run

35% total savings

Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	0.04	0.04	0.47	1.14	2.56	5.14	6.78	6.36	4.53	1.83	0.54	0.05	29.49
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	1.77	1.38	0.25	0.01	-	-	-	-	-	-	0.07	1.81	5.29
HP Supp.	0.02	0.04	0.00	-	-	-	-	-	-	-	-	0.08	0.15
Hot Water	0.27	0.25	0.29	0.27	0.26	0.23	0.21	0.21	0.18	0.22	0.22	0.24	2.85
Vent. Fans	1.41	1.27	1.41	1.36	1.41	1.36	1.41	1.41	1.36	1.41	1.36	1.41	16.58
Pumps & Aux.	0.06	0.05	0.02	0.01	-	-	-	-	-	-	0.02	0.06	0.22
Ext. Usage	0.06	0.05	0.05	0.05	0.04	0.04	0.04	0.06	0.06	0.06	0.06	0.06	0.64
Misc. Equip.	1.98	1.79	2.07	1.98	2.07	1.98	1.98	2.15	1.81	2.07	1.89	1.90	23.67
Task Lights	0.22	0.19	0.23	0.22	0.23	0.22	0.22	0.24	0.20	0.23	0.21	0.21	2.57
Area Lights	1.26	1.10	1.26	1.15	1.19	1.13	1.15	1.26	1.06	1.26	1.17	1.21	14.19
Total	7.09	6.17	6.05	6.18	7.75	10.09	11.79	11.69	9.19	7.07	5.54	7.03	95.65

- Total Electric Consumption: 95.65 (kwh x000)
- Site EUI: 33.1 KBTU/SQFT-YR GROSS-AREA
- Source EUI: 99.4 KBTU/SQFT-YR GROSS-AREA

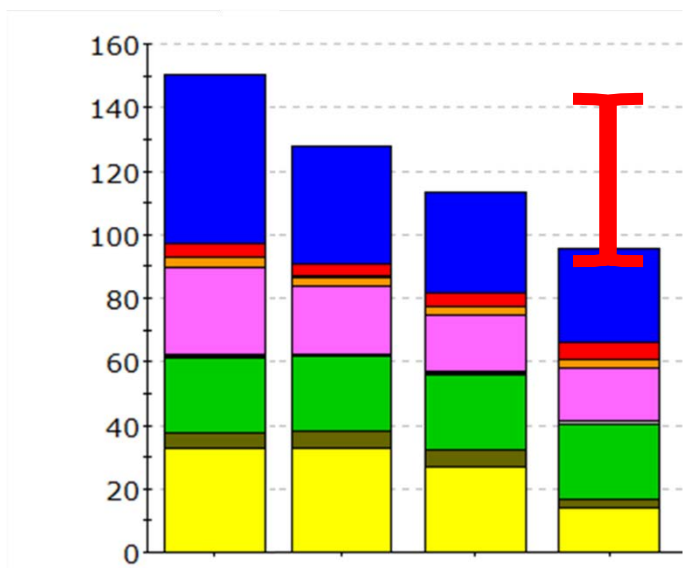


Figure 41: 35% Energy Savings Run

55% total savings

Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	0.16	0.14	0.53	1.01	1.90	3.35	4.29	4.03	3.13	1.58	0.62	0.18	20.92
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	0.65	0.40	0.04	-	-	-	-	-	-	-	0.00	0.70	1.79
HP Supp.	0.01	0.01	0.00	-	-	-	-	-	-	-	-	0.04	0.07
Hot Water	0.27	0.25	0.29	0.27	0.26	0.23	0.21	0.21	0.18	0.22	0.22	0.24	2.85
Vent. Fans	1.61	1.46	1.61	1.56	1.61	1.56	1.61	1.61	1.56	1.61	1.56	1.61	18.99
Pumps & Aux.	0.09	0.08	0.02	0.01	-	-	-	-	-	-	0.02	0.09	0.31
Ext. Usage	0.06	0.05	0.05	0.05	0.04	0.04	0.04	0.06	0.06	0.06	0.06	0.06	0.64
Misc. Equip.	0.98	0.89	1.02	0.98	1.02	0.97	0.98	1.06	0.89	1.02	0.93	0.94	11.68
Task Lights	0.42	0.38	0.44	0.42	0.44	0.42	0.42	0.46	0.38	0.44	0.40	0.40	5.02
Area Lights	0.73	0.66	0.76	0.72	0.76	0.72	0.73	0.79	0.66	0.76	0.69	0.69	8.67
Total	4.98	4.31	4.76	5.02	6.03	7.30	8.28	8.23	6.87	5.69	4.51	4.97	70.94

- Total Electric Consumption: 70.51 (kwh x000)
- Site EUI: 24.4 KBTU/SQFT-YR GROSS-AREA
- Source EUI: 73.3 KBTU/SQFT-YR GROSS-AREA

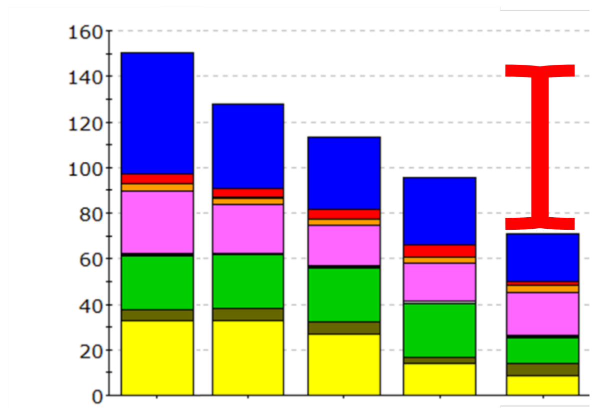


Figure 42: 55% Energy Savings Run

10. Cost Analysis

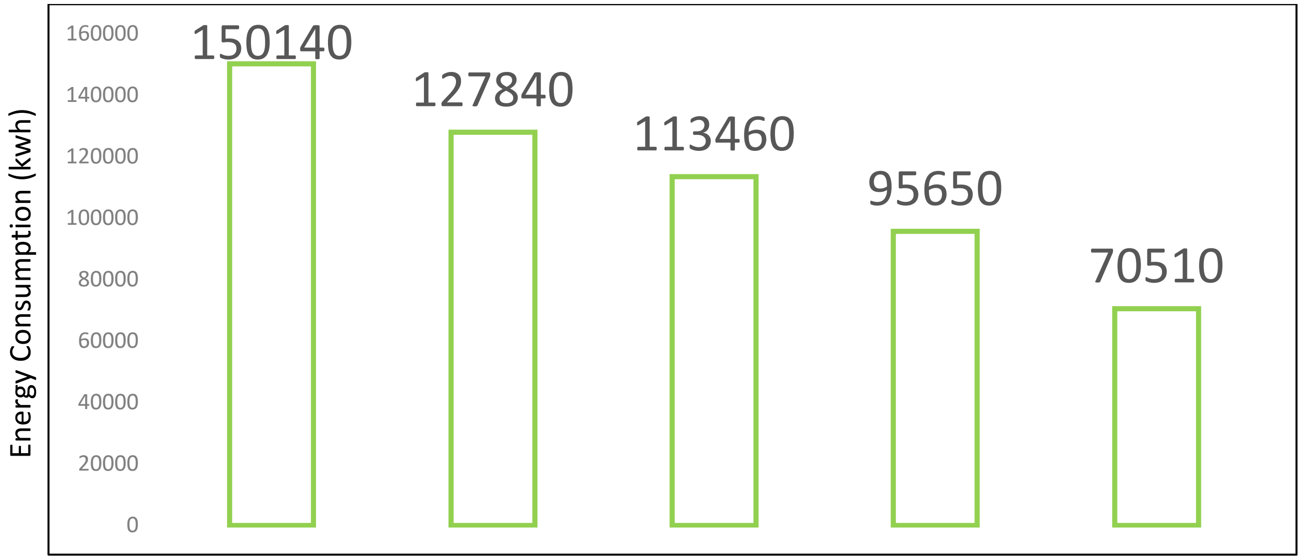


Figure 43: Energy Consumption, All Runs

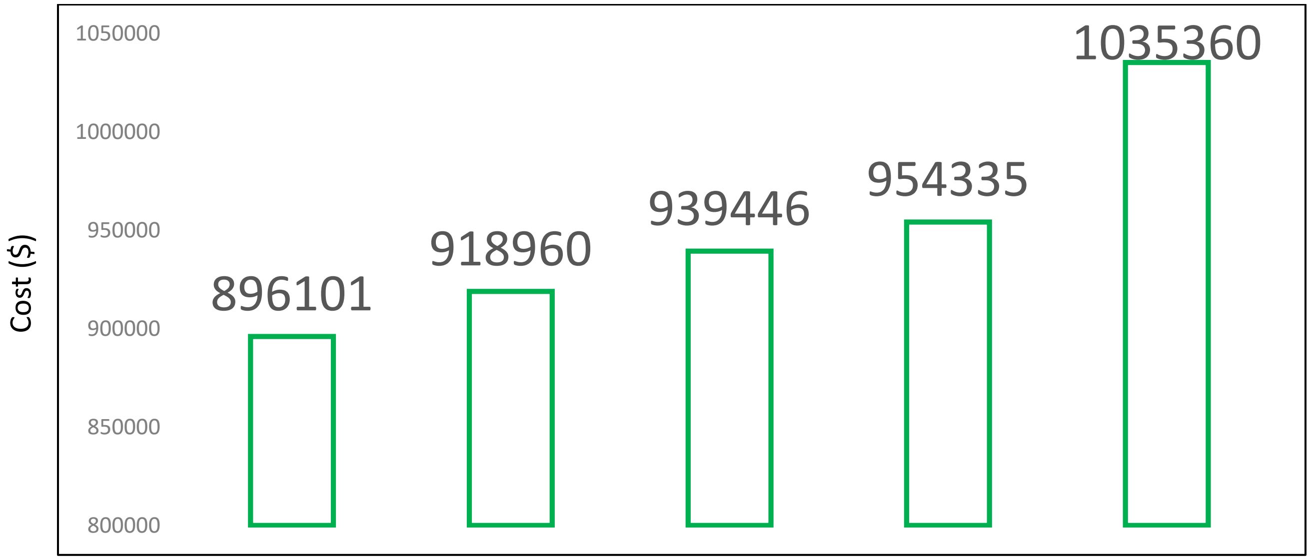


Figure 44: Total Cost, all runs

The two graphs above show the relationship between cost and energy efficiency. The more energy a building is saving, the greater the capital investment needed to reach that point.

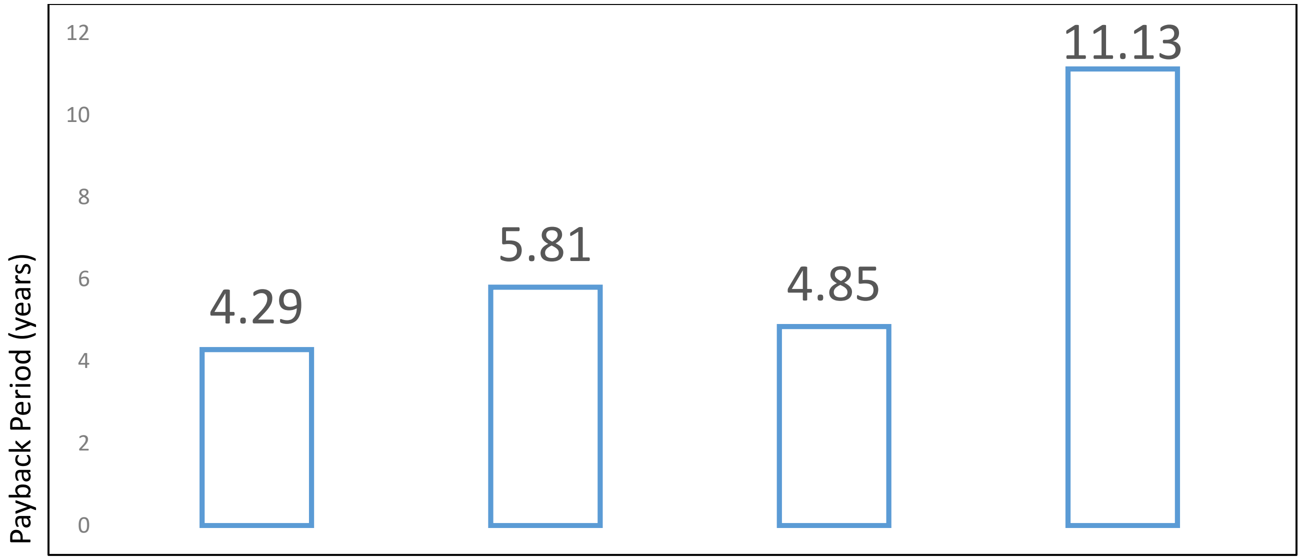


Figure 45: Payback Period, all runs

The payback period in most cases is desired somewhere between 4-7 years. Giving up 2 or 3 additional years of full payback for a building is acceptable due to the increased resiliency and lifespan of the building.

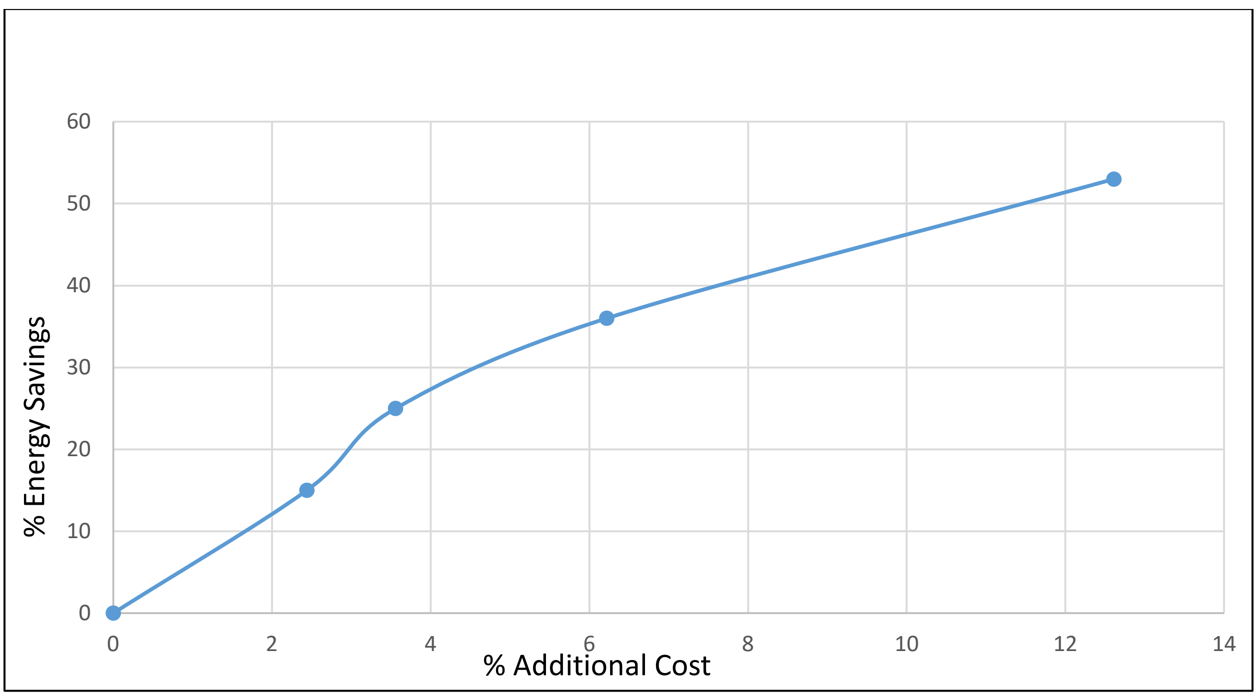


Figure 46: Cost vs. Energy Savings

This is the graph of diminishing returns for the energy efficiency strategies showing the optimized point of investment. Any further, and energy savings would begin to flat line as costs continue to increase. This point on the graph references the building iteration with a site EUI of 24.4. Considering similar strategies, the optimal EUI range can be extended to between 22 and 26kbtu/sqft/yr. This would be the energy performance goal and a building within this range can be considered pre net-zero status if this was achieved through cost effective means. Taking the data from Figure 46, the range of acceptable ratios of additional cost investment to energy savings (energy savings divided by additional cost) is between 3.75 and 4.25. This ratio indicates a feasible investment that results in favorable payback periods and savings.

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